Alternative risk thresholds for South African sardine and anchovy resources

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This document considers alternative biomass-related risk thresholds for use in tuning Candidate Management Procedures for the South African sardine and anchovy resources. The document is written to provide background information to the key question to the panel "How do we best choose risk thresholds in terms of biomass levels for sardine and anchovy"?

Background

The control parameters of the joint Operational Management Procedures (OMPs) for South African sardine and anchovy have historically been tuned so that the simulated future biomass avoids a pre-specified risk threshold with a selected probability.

While OMP-99 and OMP-02 used risk thresholds linked to the estimated baseline carrying capacity, *K*, of each resource, the uncertainty surrounding the estimation of *K* for small pelagics resulted in the subsequent three joint OMPs being tuned to the following risk thresholds:

$\underline{Risk^{S}_{past}}$: average total sardine 1+ biomass between November 1991 and 1994

$\underline{Risk^{A}_{past}}$: 10% of average anchovy 1+ biomass between November 1984 and 1999.

The sardine risk threshold was primarily informed by the observation that the resource was able to (rapidly) increase after this 1991 to 1994 period (Figures 1a and 2a). However, with the resource now considered to consist of two mixing components, rather than a single homogeneously distributed stock, the increase in the resource to peak levels can no longer be linked simply to the 1991 – 1994 total (or west component) biomass levels. In addition, the west component biomass levels have been below the 1991 – 1994 average for many years since 2004.

The anchovy risk threshold was roughly informed by the observation that the resource since ~2000 has been at a higher "recruitment regime" than that observed during the earlier years of the time series. The low proportion of this 1984 to 1999 average was selected due to the high variability in simulated future biomass (due to high variability in simulated future recruitment) and hence the relatively high probability of dropping below the average during such simulations even under no catch scenarios.

Alternative Thresholds

For the west sardine component, four new risk thresholds have been considered thus far.

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$\underline{Risk^{S}_{2007}}$: The 2007 total biomass. This is the lowest estimated posterior median total biomass between 1984 and 2015 (Figure 3) and future projections should avoid going below this historically lowest level with high probability. This threshold is self-consistent in that the value used differs for each simulation of each Operating Model (OM) depending on the corresponding model fit to the historical data. Note that the lowest survey estimate of biomass of 25 500t was in 1985 (Figure 1).

$\underline{Risk^{S}_{70}}$: 70 000t spawner biomass. This is a value which roughly corresponds to a point below the median hinge point of the hockey stick stock recruitment relationship (Figure 4). Note, however, that the stock recruitment relationship – and in particular its hinge point - differs for each simulation of each OM. Thus 70 000t does not necessarily correspond to a point below the hinge point for every simulation.

$\underline{Risk^{S}_{100}}$: 100 000t spawner biomass. This is a value which roughly corresponds to the median hinge point of the hockey stick stock recruitment relationship (Figure 4). Note, however that the stock recruitment relationship – and in particular its hinge point - differs for each simulation of each OM. Thus 100 000t does not necessarily correspond to the hinge point for every simulation.

$\underline{Risk^{S}_{hinge}}$: The actual hinge point of the hockey stick stock recruitment relationship. This the spawner biomass level below which median recruitment is reduced (Figure 5). The hinge point is assumed to be robustly estimated (see Appendix).

Given the concern for the west component of the resource as it provides the primary source of recruitment to the whole population; this has been the focus of recent analyses so that a risk threshold for the south sardine component has yet to be considered.

When testing candidate MPs assuming a single sardine stock OM, the above $Risk^{S}_{2007}$ and $Risk^{S}_{hinge}$ can be easily calculated for total (spawner) biomass.

For anchovy one new risk thresholds has been considered thus far.

$\underline{Risk^{A}_{1996}}$: A quarter of the 1996 total biomass. 1996 is the lowest estimated posterior median total biomass between 1984 and 2015 (Figure 6) and future projections should avoid going below this historically lowest level with high probability. However, given the high variability in future projections (see below) 25% of the 1996 total biomass was selected as a threshold. This threshold is self-consistent in that the value used differs for each simulation of each OM depending on the corresponding model fit to the historical data.

Results and Discussion

Assuming no future fishing, the simulated future sardine biomass indicates, under a two component OM with 20% of south coast spawner biomass contributing to west coast recruitment (i.e. the $p = 0.2$ scenario), a 0.06

probability of being below $Risk^S_{2007}$ over 2017-2036 (Figure 3), a 0.12 probability of being below $Risk^S_{70}$, a 0.21 probability of being below $Risk^S_{100}$ and a 0.22 probability of being below $Risk^S_{hinge}$ (Figure 7).

In some regions of the world it appears that the lowest historically observed (spawner) biomass is taken as a B_{lim} and future catch limits are set with a high probability of avoiding the lowest historical level. This is based on the concern that the shape of the stock-recruitment curve is not well known, let alone estimated, for low spawning biomasses, particularly in cases where estimates of recruitment do not indicate a clear strong relationship with spawner biomass. Thus the impact on recruitment of a decrease in spawner biomass below the lowest historical level is scarcely known.

"Dynamic B_0" is understood to be the biomass that would have been present had there been no (historical and future) fishing, and requires projection over the model conditioning period starting from an unexploited equilibrium (South African sardine and anchovy were harvested prior to 1983). Such a method, given assumptions regarding the initial status of the resource, could provide a risk threshold, for example 20% of dynamic B_0 as a limit reference point. However, calculating dynamic B_0 for the full posterior distribution has logistical complications. Projections assuming no future catch are, however, routinely considered for all OMs. These projections could be considered to provide an estimate of dynamic B_0 after a sufficiently long period such that the transient effects relating to the initial projection year are removed. However, comparisons to such a risk threshold in the short- to medium-term would then not be appropriate.

The projected anchovy biomass has a very wide distribution, in part due to the high variability about the stock recruitment relationship and associated autocorrelation (Figure 8). This results in a high probability of dropping below the historically observed lowest level (1996), and even a quarter of this threshold, even in the absence of fishing (Figures 6 and 9). However, tuning an OMP to allow for a relatively high probability of dropping below a low threshold such as $Risk^A_{past}$ or $Risk^A_{1996}$ naturally causes much unease amongst some stakeholders.

Discussion Points

Discussion (including drawing from examples in fisheries where the panel have worked) and recommendations towards the following questions are sought:

i) How should we best define a risk threshold for the sardine west component?

ii) How (if necessary) should we best define a corresponding risk threshold for a single stock hypothesis for sardine?

iii) How should we best define a risk threshold for anchovy?

In addition, if time permits

i) How important would it be to define a risk threshold for the sardine south component?

References

de Moor CL and Butterworth DS. 2012. Assessment of the South African sardine resource using data from 1984-2011, with some results for a single stock hypothesis. DAFF: Branch Fisheries Document FISHERIES/2012/SEP/SWG-PEL/48.

de Moor CL and Butterworth DS. 2016a. Assessment of the South African sardine resource using data from 1984-2015: Results at the joint posterior mode for the two mixing-stock hypothesis. DAFF: Branch Fisheries Document FISHERIES/2016/JUL/SWG-PEL/22REV2.

de Moor CL and Butterworth DS. 2016b. Assessment of the South African sardine resource using data from 1984-2015: Results at the joint posterior mode for the single stock hypothesis. DAFF: Branch Fisheries Document FISHERIES/2016/JUL/SWG-PEL/23REV.

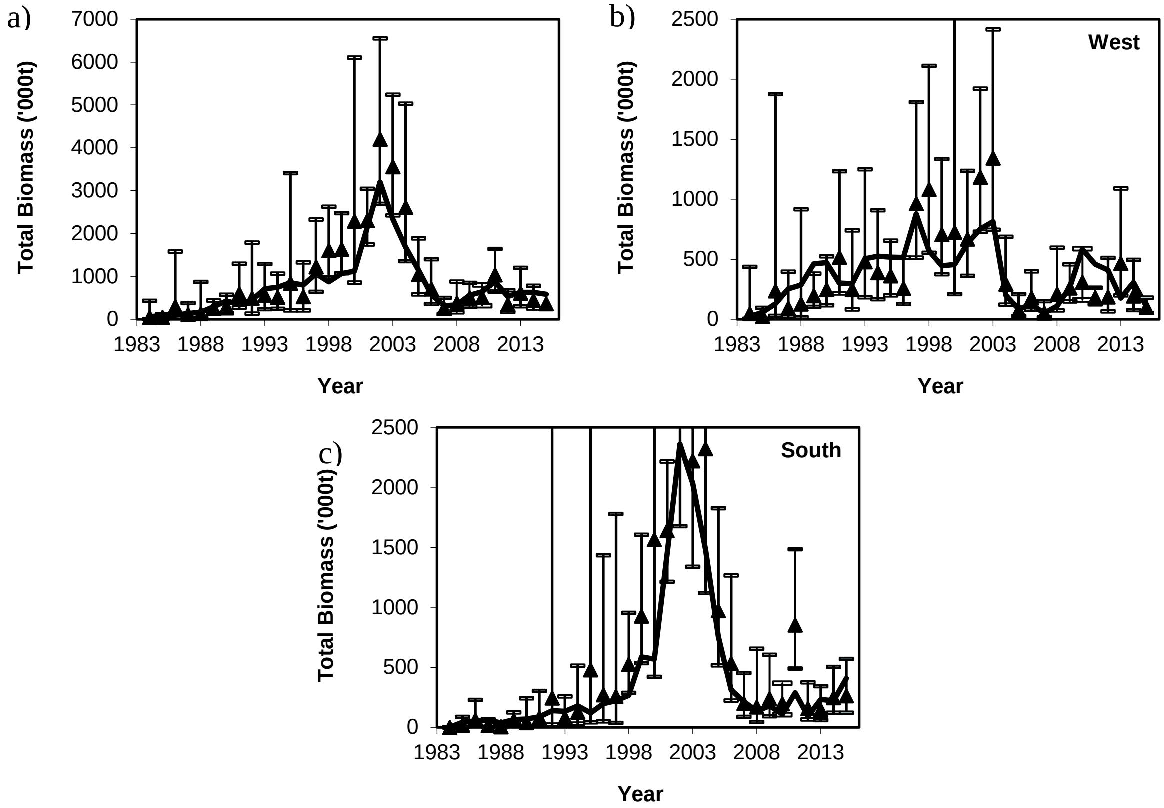


Figure 1. Acoustic survey estimated and model predicted **November sardine total biomass** from 1984 to 2015 for a) single stock hypothesis (de Moor and Butterworth 2016b), b) west component and c) south component (de Moor and Butterworth 2016a). The observed indices are shown with 95% confidence intervals.

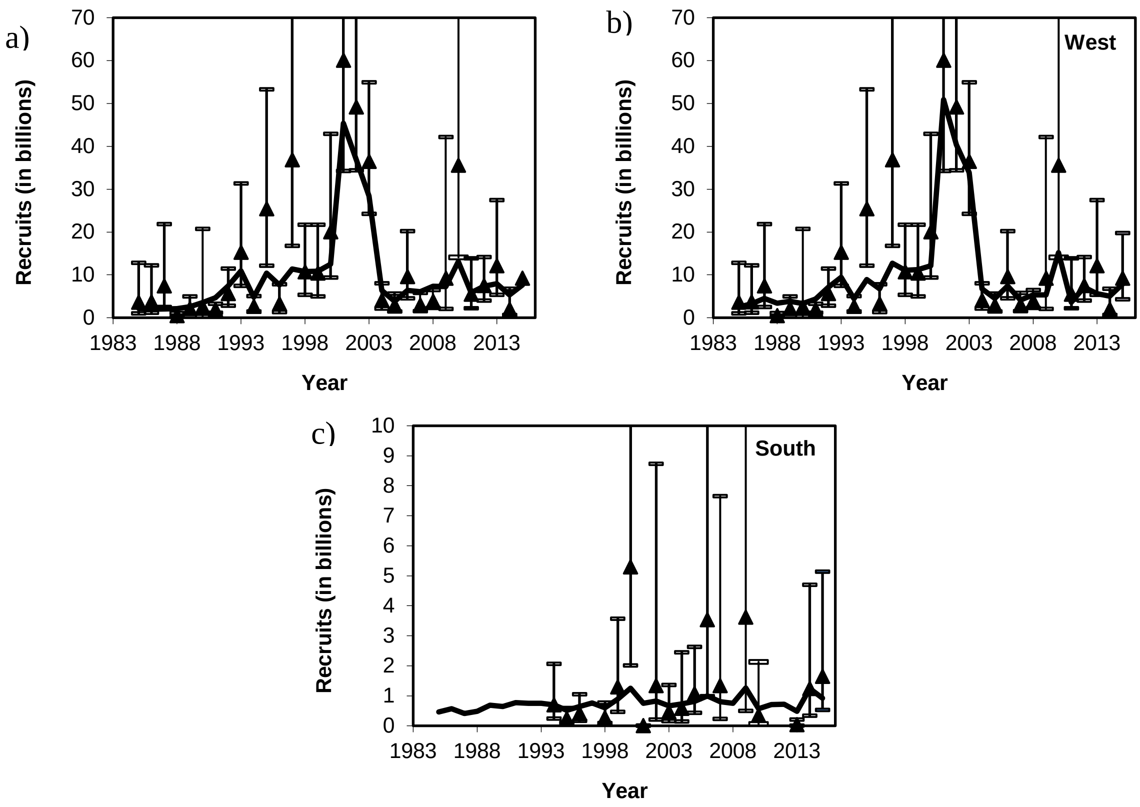


Figure 2. Acoustic survey estimated and model predicted **sardine recruitment numbers** from May 1985 to May 2015 for a) single stock hypothesis (de Moor and Butterworth 2016b), b) west component and c) south component (de Moor and Butterworth 2016a). The survey indices are shown with 95% confidence intervals.

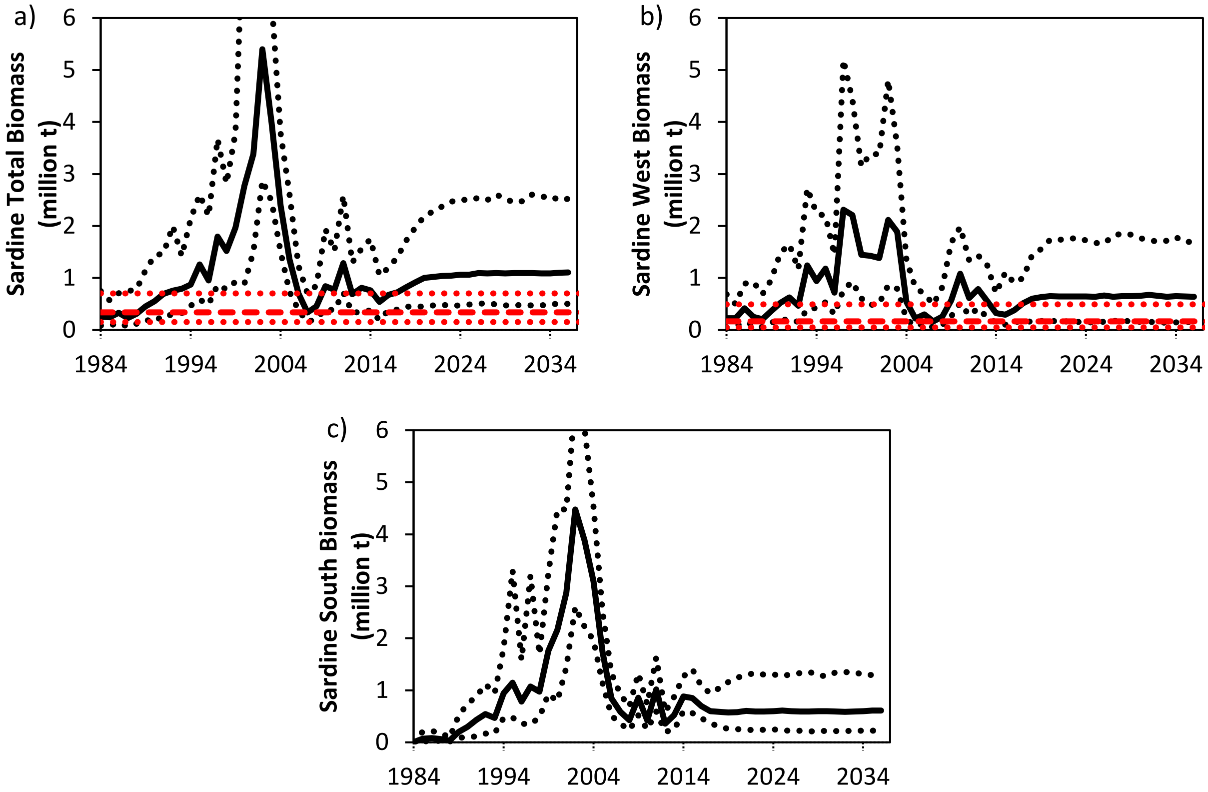


Figure 3. The posterior median and 95% probability intervals of sardine total biomass for a) the single stock hypothesis, b) the west component and c) the south component from the OM in which the stock recruit relationship is estimated externally from the assessment and 20% of the south coast spawner biomass is assumed to contribute to west recruitment. The red horizontal lines correspond to the median and 95% probability intervals for the 2007 biomass.

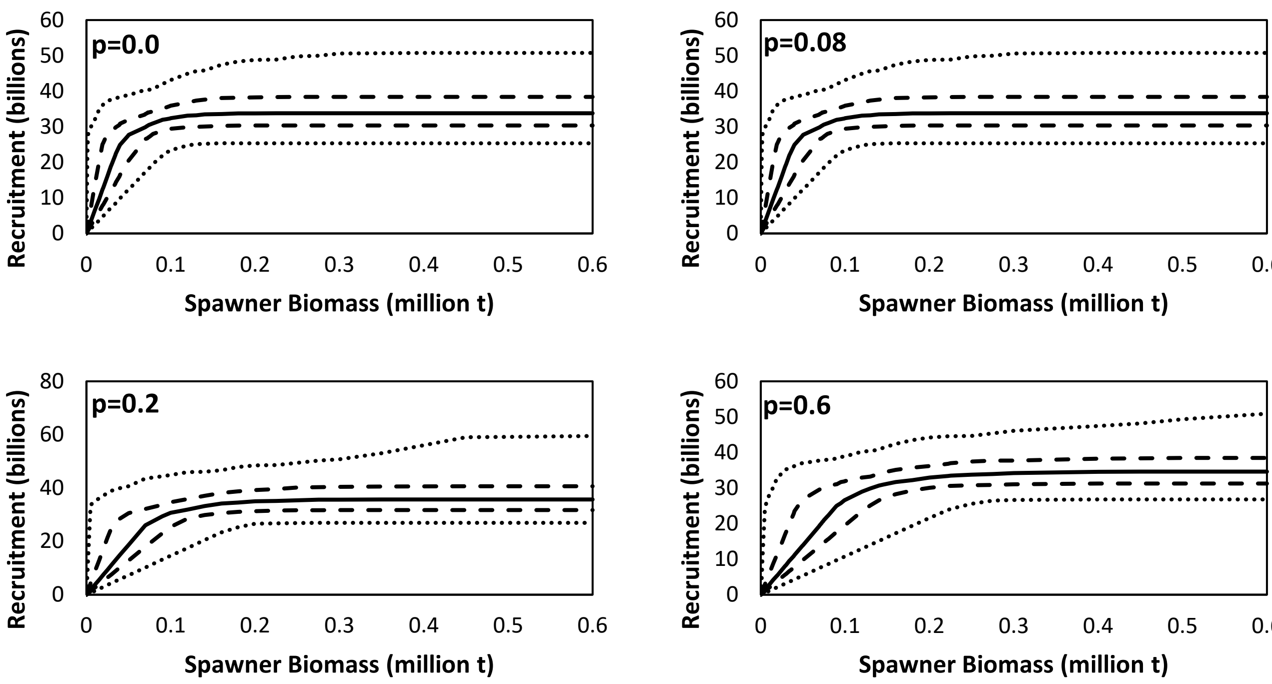


Figure 4. The median, 50% and 95% probability intervals for the sardine west component hockey stick stock recruitment relationships (for a range of proportions, *p*, of south coast spawner biomass contributing to west coast effective spawner biomass), where these are estimated after the model conditioning.

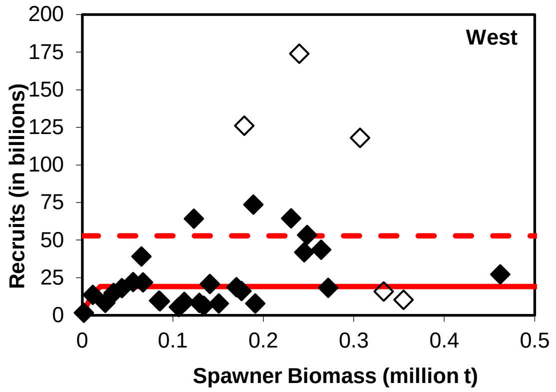


Figure 5. The estimated hockey stick stock-recruitment relationships at the joint posterior mode for the two component hypothesis with 20% of south coast spawner biomass contributing to west coast effective spawner biomass (i.e. the $p = 0.2$ scenario). The dashed line indicated the median recruitment estimated for west component pulse (open diamond) years.

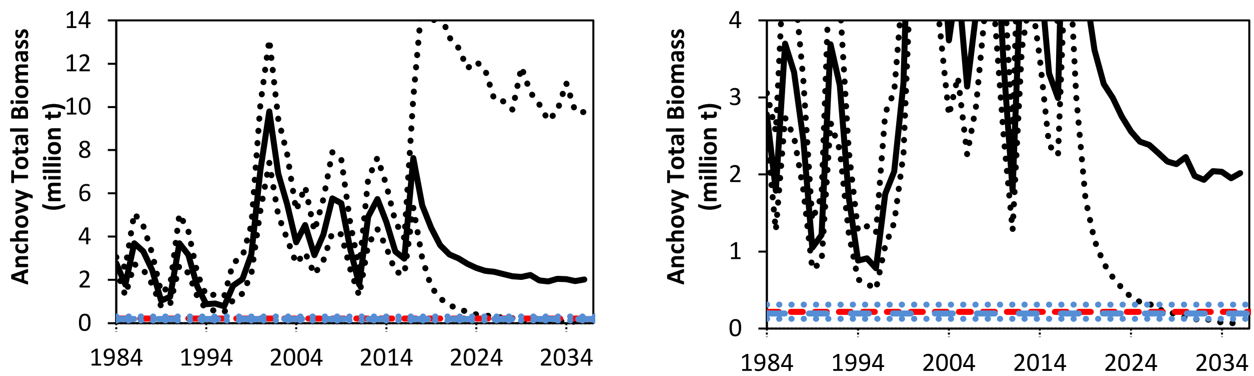


Figure 6. The posterior median and 95% probability intervals of anchovy biomass. The median of 10% of the average 1984 to 1999 biomass is denoted by the red dashed line. The median and 95% probability intervals of 25% of the 1996 biomass are denoted by the blue dashed and dotted lines, respectively. The right plot is a repeat of the left one, but with a smaller vertical axis scale.

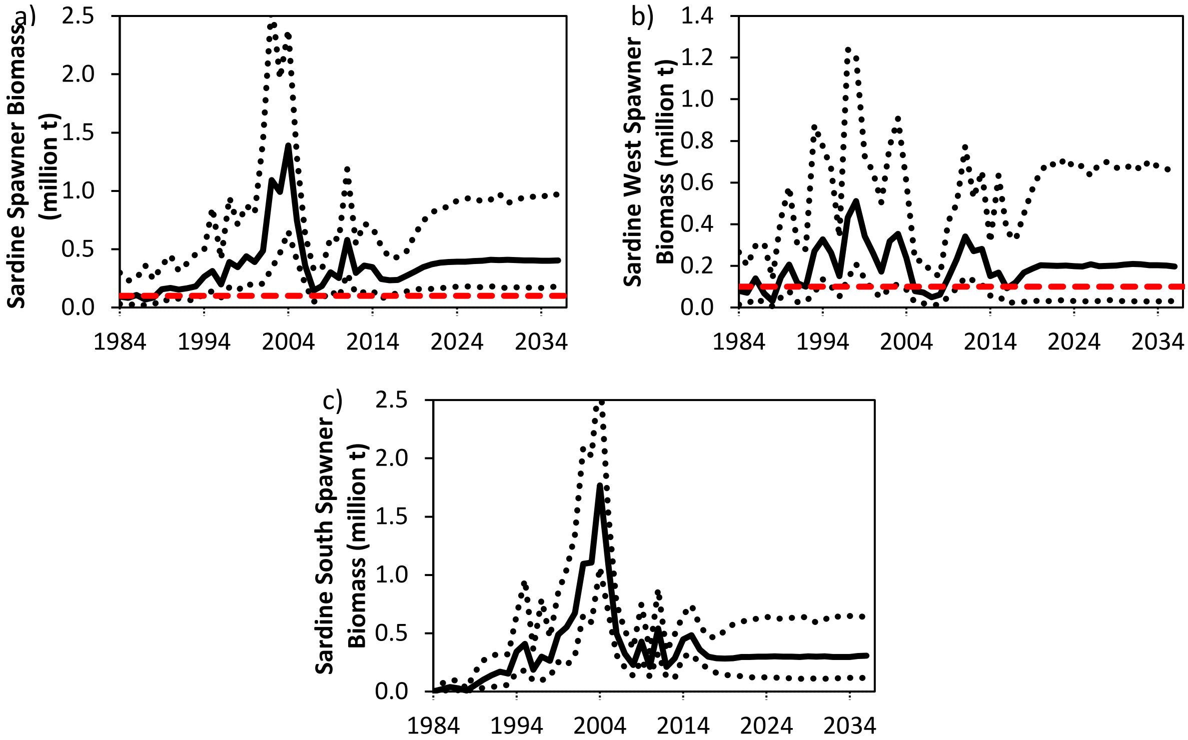


Figure 7. The posterior median and 95% probability intervals of sardine spawner biomass for a) the single stock hypothesis, b) the west component and c) the south component from the OM in which the stock recruit relationship is estimated externally from the assessment and 20% of the south coast spawner biomass is assumed to contribute to west recruitment (i.e. the $p = 0.2$ scenario). The red horizontal line corresponds to $\underline{\text{Risk}^{S}_{100}}$ = 100 000t.

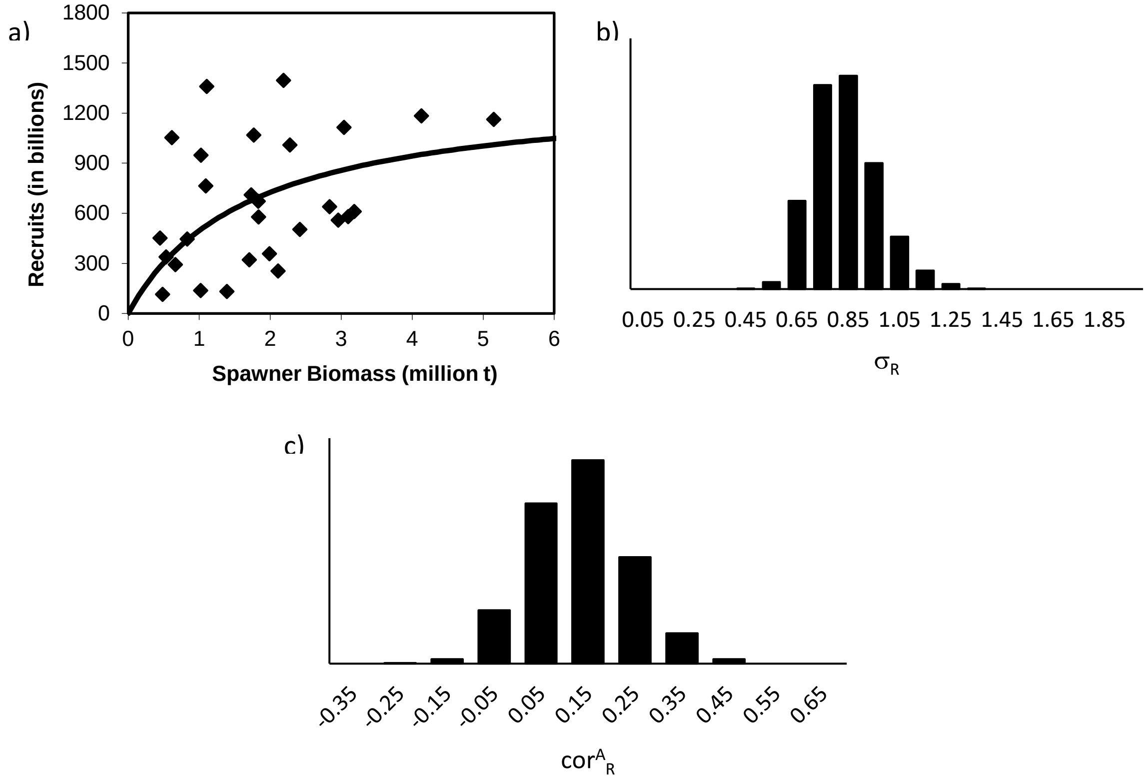


Figure 8. The a) estimated Beverton Holt stock-recruitment relationship at the joint posterior mode for anchovy, b) the posterior distribution of standard deviation about the anchovy stock recruitment relationship, and c) the posterior distribution of autocorrelation amongst stock recruitment residuals.

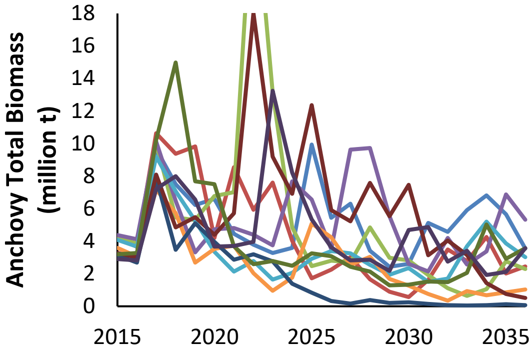


Figure 9. Some individual realisations (worm plots) of future anchovy biomass under a no catch scenario.

<u>Appendix</u>. How reliably is the Hockey Stick hinge point estimated?

There has been a substantial downward shift in the hinge point of the Hockey Stick stock recruitment relationship from that estimated for the baseline OM used to develop OMP-14 to that more recently estimated and to be used to simulation test candidate MPs for OMP-18 (Figure A1). The estimation of this hinge point, particularly at such a relatively low spawner biomass level, is of importance as it relates in some way to a limit reference point. Underestimation of the hinge point could result in risky management as a candidate MP would be tuned to an acceptable level of risk assuming that recruitment is not impaired at a level lower than at which it is actually impaired in reality. This higher risk to the resource could have additional potential consequential negative impacts on future catches as well as the wider ecosystem in terms of dependent predators, for example. On the other hand, if the hinge point is overestimated, then subsequent management of the resource could result in under-harvesting.

We defined a non-parametric stock recruitment relationship using a Gaussian kernel smoother with the additional assumption of a straight line from the origin to the recruitment corresponding to $minB = min\left(SSB_{j,y}^{S}\right)$, $1986 \leq y \leq 2014$[1], thus:

$$ln\left(N_{j,y}^{pred}\right) = \begin{cases} \frac{Smoother_{minB}}{minB} \times SSB & if\ SSB < minB \\ Smoother_{SSB} & if\ SSB \geq minB \end{cases} \qquad (A.1)$$

where

$$Smoother_{SSB,j} = \frac{\sum_{y=1986}^{2014} ln\left(N_{j,y}\right) \times exp\left\{\frac{-\left[ln\left(SSB_{j,y}\right) - ln(SSB)\right]^2}{\theta^2}\right\}}{\sum_{y=1986}^{2014} exp\left\{\frac{-\left[ln\left(SSB_{j,y}\right) - ln(SSB)\right]^2}{\theta^2}\right\}} \qquad (A.2)$$

with $\theta = 0.8$.

This relationship generally represents the broad trends in the data well, although it displays a non-convex shape for some of the realisations (Figure A2) which is an unreasonable property if such a curve is to be considered in isolation as a realistic representation of reality and used as a baseline OM. However, in considering the posterior distribution of the estimated non-parametric stock recruitment relationship against that of the Hockey Stick stock recruitment relationship, one can see that the non-parametric relationship estimates a similar proxy hinge point to that of the Hockey Stick curve, indicating that this hinge point (below which sardine recruitment is impaired) is reasonably well estimated given data from 1984-1999 and 2005-2015.

[1] 2000-2004 pulse years were excluded for the west component.

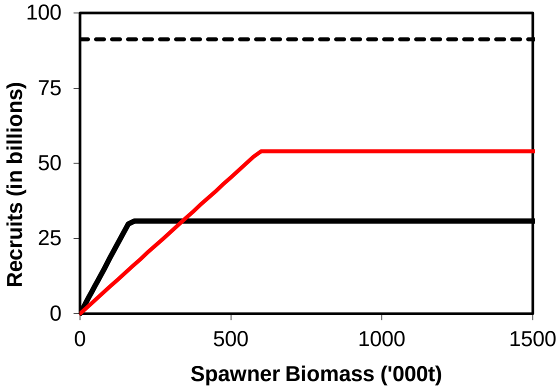


Figure A1. The hockey-stick stock recruitment relationship estimated at the joint posterior mode for a single sardine stock hypothesis using data from 1984 to 2011 (red, de Moor and Butterworth 2012) and using data from 1984 to 2015 (black, de Moor and Butterworth 2016b). The black dashed line is the median pulse year (2000-2004) of recruitment estimated during the recent assessment.

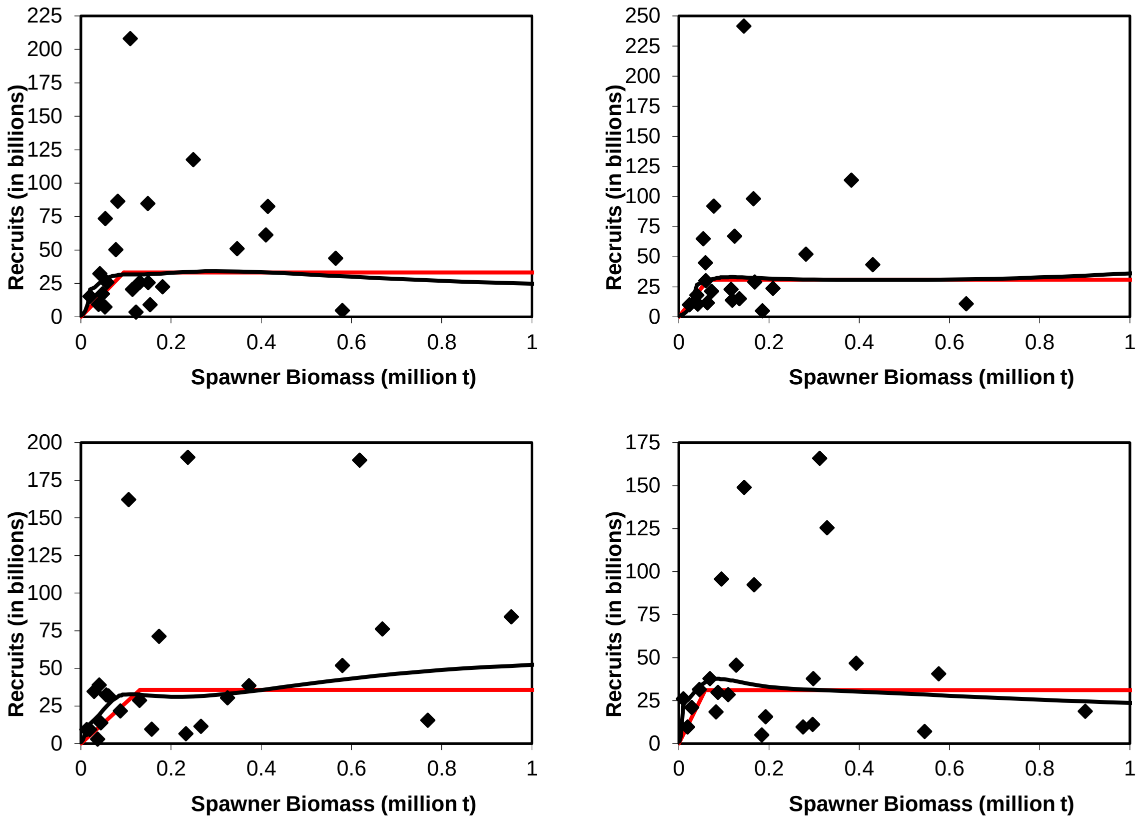
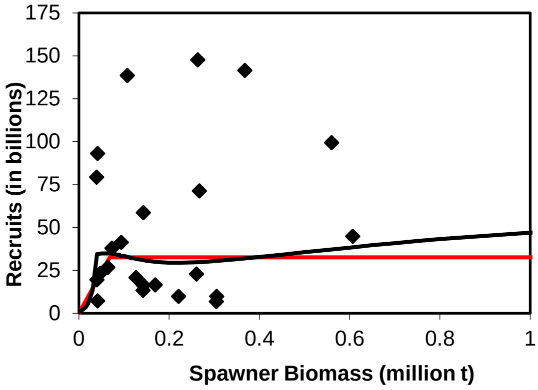
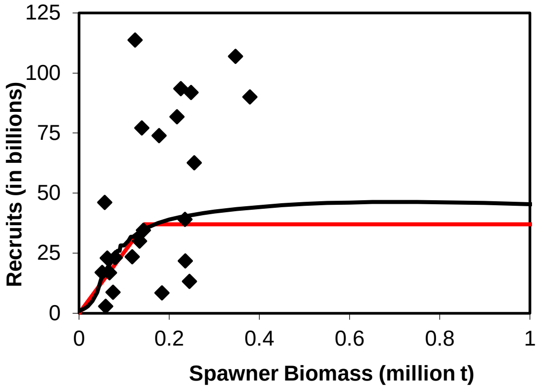
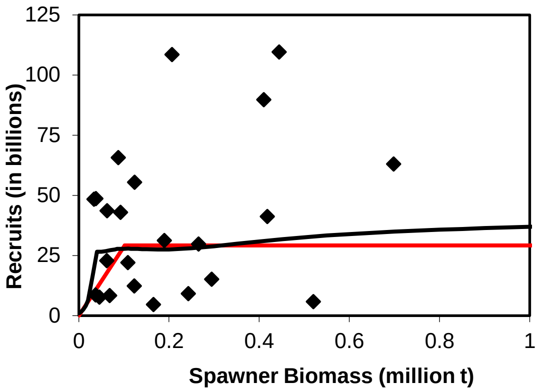


Figure A2. Comparisons between the hockey stick (red) and non-parametric (black) relationships for 8 of the 1000 simulations drawn from the posterior distribution for the west component. The diamonds indicate the 'data' excluding the pulse years.







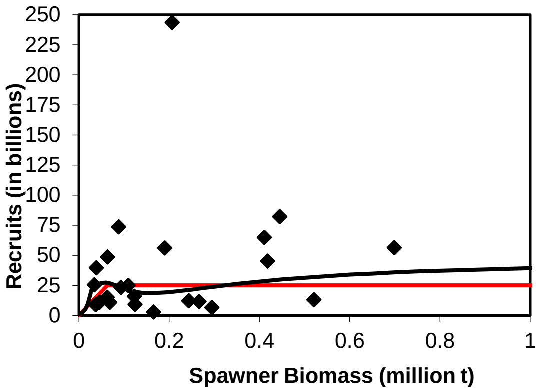


Figure A2 (continued).

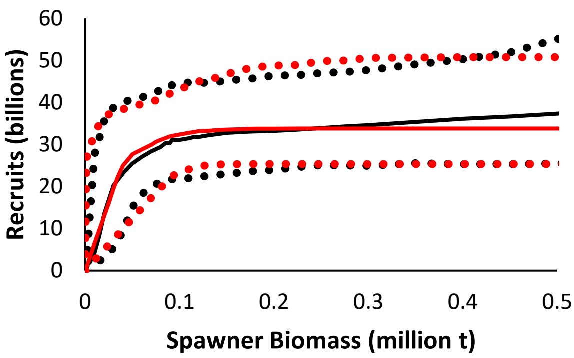


Figure A3. Posterior median and 95% probability intervals for the hockey stick (red) and non-parametric (black) stock recruitment relationships for the west component of sardine assuming no south coast spawner biomass contribution to west coast recruitment.